E-298

REVIEW OF INFORMATION ON THE INSECTICIDAL VALUE OF ROTENONE

By F. L. Campbell, Bureau of Entomology,
U. S. Department of Agriculture

Table of Contents

Foreword

The widespread interest in rotenone and the contradictory results that have been obtained by various workers of the Bureau and referred to in their monthly reports have emphasized the desirability of summarizing available information on the insecticidal value of rotenone.

Information secured from various workers was referred to Doctor F. L. Campbell. His study of this unpublished information and of published articles on rotenone should aid those interested in carrying on further work with this new insecticide.

For obvious reasons the details of all the experiments are not reported but essential results are. In referring to these experiments credit should be given to the original observer rather than to the compiler. In addition to summarizing the data at hand, the compiler has discussed results and suggested lines of research. - C. L. M.

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Stomach action

Toxicity. Davidson[2] has tested rotenone as a stomach poison against 9 species of leaf eating insects. His summary of results is given in Table 1. Since not more than 10 insects were used in each test, and since the quantity of rotenone consumed by the insects was not determined, the relative susceptibility of the different species to rotenone can not be definitely stated. However, Table 1 does show that rotenone acts as a stomach poison against certain insects and that some species are decidedly more susceptible to rotenone than others. Larvae of the following species were killed by rotenone: Eastern tent caterpillar,[3] silkworm, imported cabbage worm, and Mexican bean beetle. Adults of the following species were killed: Mexican bean beetle, Colorado potato beetle, and striped cucumber beetle. The squash beetle (adult) was affected but not killed. Neither the spotted cucumber beetle (adult) nor the differential grasshopper (nymphs) was affected by rotenone.

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[1] Information on physical, chemical, botanical, pharmacological, and commercial aspects of rotenone will be found in a companion review by C. M. Smith of the Insecticide Division of the Bureau of Chemistry and Soils. R. C. Roark, in charge of this Division, is largely responsible for the present interest in rotenone as an insecticide, having supplied rotenone or preparations containing it for most of the tests herein described.

[2] Unpublished information was supplied by workers who are named in the text and in Appendix 1. Published results are indicated by the usual form of citation.

[3] Common names of insects are used in the text and are listed in Appendix 2, together with their scientific names and the names of the workers who made observations on the insects.

Table 1. Davidson's tests of rotenone in suspension as a stomach poison.

Insect	Stage	Concentration	Method of feeding	Period of exposure	Result
		gram: c.c.		days	
		1:1000		5/24	Feeding curtailed
		1:100		6	All killed
Eastern tent		1:100 + soap	Sandwich	do	do
caterpillar	IV	1:200		do	do
		1:200 + soap		do	do
		1:400		do	do
		pure dust		1	do
		1:1000		1	All killed
Silkworm	III	1:2000	do	5	40 per cent killed
		1:5000		1	do
Imported		1:1000		1	All killed
cabbage worm	V	1:5000	do	6	20 per cent killed
Mexican		1:200	do	4	All killed
bean beetle	Larva				
Colorado		1:200		5	All killed
potato beetle	Adult	1:500	do	5/24	Feeding curtailed
		1:1000		do	do
		pure dust		3	All killed
Differential		1:210		5 to 15	No effect
grasshopper	III	1:500	Plant	11 to 15	do
		1:1000	sprayed	13 to 28	Slight value
		1:200		7	No feeding
Squash beetle	Adult	1:500	do	do	do
		1:1000		9	Feeding curtailed
		1:2000		do	do
Mexican		1:5000	do	4	All killed
bean beetle	do	1:10,000		10	90 per cent killed
Colorado		1:10,000	do	5	No effect
potato beetle	do				
Spotted cucum-		1:125	do	9	No effect
ber beetle	do	1:250		7	do
		1:1000		9	do
Striped cucum-		1:125		5	All killed
ber beetle	do	1:250	do	7	do
				do	do
				9	50 per cent killed
				do	No effect

The first experiment in Table 1 is of particular interest. Ten larvae at the beginning of the fourth stadium were used, one larva to a Petri dish. Each larva was given an apple leaf sandwich (5/8 in. diam.) containing about 0.002 c.c. of a 1:1000 suspension of rotenone. Therefore each sandwich probably contained about 0.002 mg. of rotenone. The larvae ate from 1/8 to 1/3 of the sandwiches and therefore probably did not consume more than 0.001 mg. of rotenone. All but one of these larvae finally died. If they weighed about 0.1 gram, they were killed by doses of about 0.005 mg. of rotenone per gram of body weight. This calculation is very uncertain, but it suffices to show that rotenone is much more toxic to tent caterpillars than is acid lead arsenate. Preliminary results obtained by Bulger indicate that a dose of at least 0.15 mg. of acid lead arsenate per gram of body weight of tent caterpillar in the last instar is required to kill 50 per cent of a population, or in other words, that the median lethal dose is greater than 0.15 mg. per gram.

More precise results were obtained by Campbell with the fourth instar silkworm. Using the sandwich method as described by Campbell and Filmer (3), Campbell found the median lethal dose of rotenone to be about 0.003 mg. per gram. Since the median lethal dose of acid lead arsenate for the fourth instar silkworm is about 0.09 mg. per gram, rotenone is about 30 times more toxic than acid lead arsenate for this insect. In two of his tests, Davidson did not kill all the silkworms. In the absence of information on the quantity of rotenone consumed by the insects in these tests, it is impossible to say whether or not his results are similar to those of Campbell.

Davidson made 15 tests of rotenone as a stomach poison against house flies. Eight tests were made in screen cages in a greenhouse and seven in a room of 500 cu. ft. Rotenone was dissolved in acetone and added to diluted condensed milk or to a dilute solution of molasses. Cotton was soaked in the mixtures and exposed in Petri dishes to the flies. The food was not renewed during the period of a test. Each test was paired with a check, in which flies were given unpoisoned food. The flies used in most of the tests were between 1 and 2 days old. The numbers of flies used per test ranged between 18 and 118. In 6 tests all flies were killed during periods ranging from 28 to 72 hours. In 5 other tests more than 90 per cent were killed in 24 to 48 hours. The quantities of rotenone in the cotton ranged from 10 to 100 mg. In one test only 0.8 mg. of rotenone was used, but a mortality of 84 per cent was obtained in 94 hours. Except in one case, little or no mortality occurred in the checks. It may be concluded that rotenone will kill house flies by way of the alimentary tract, but that its toxic action is slow. Since it is possible to feed individual house flies with known volumes of rotenone suspensions, experiments should be made to determine the median lethal dose of rotenone for this insect.

If it is assumed that suspensions of poisons kill mosquito larvae by stomach action, Davidson's (6) results with culicine mosquito larvae may be mentioned here. He found that an extremely dilute suspension of rotenone (1:2,300,000) killed 95 per cent of a population of mosquito larvae exposed to it for six days. Using exposure periods of only 1/2 and 2 hours, Shepard (12) found that a 1:10,000 suspension of rotenone was more effective than the same concentration of nicotine. Although the actual doses taken can not be estimated, it is obvious that rotenone is highly toxic to culicine mosquito larvae.

Reynolds fed cabbage leaf sandwiches containing an unknown quantity of rotenone to cutworms. Although the leaf disks were treated with rotenone suspension up to 1:200, the larvae fed freely and were not affected by rotenone. This unidentified cutworm is the only lepidopterous larva so far tested that seems resistant to rotenone as a stomach poison.

C. H. Richardson as well as Davidson found that rotenone is ineffective against grasshoppers. Richardson fed rotenone in bran-molasses baits to the differential grasshopper and the red-legged grasshopper. One grasshopper took a dose of 3.9 mg. of rotenone per gram of body weight and yet lived more than 4 days. Low toxicity was also indicated by experiments with rotenone in corn leaf sandwiches. Richardson concluded that rotenone has little if any toxicity for grasshoppers.

The foregoing results show that some species of insects may be susceptible to rotenone and that others may be resistant. Quantitative experiments are needed on many species to indicate the range of susceptibility of insects to rotenone as stomach poison.

Repellent effect. In all his tests Davidson was watching for a repellent action of rotenone on the insects. In order to discuss his results, it is necessary to define "repellent" because the term has been used loosely. Many entomologists, including the writer, define "repellent" as a substance that prevents an insect from feeding or ovipositing upon its host without otherwise injuring the insect. Repellent action in this sense can be detected only when the insect is offered a choice between a treated and untreated host. When the insect is confined with the treated host only and does not feed, its subsequent death may be attributed either to insecticidal action by contact or fumigation, or to starvation, and repellent action is thereby obscured. When insects do feed on the treated host and consume sublethal doses, they may be so affected that they are forced to leave the treated host. The writer would prefer to call this response a deterrent effect rather than a repellent effect, because the insect is not driven away until it is poisoned. Deterrent action also can be detected only when the insect is given an opportunity to leave the treated host and go to an untreated host. The factor of chance distribution of the insects between treated and untreated hosts would of course have to be considered in deciding whether or not insects are repelled or deterred by a poison.

Davidson made an experiment with rotenone against Colorado potato beetles. The insects were given an opportunity during a period of 5 hours to feed on potato leaf sandwiches containing rotenone. Thereafter they were fed untreated leaf disks for 8 days. The mortality was negligible, but it was observed that the beetles ate less of the rotenone sandwiches than of those containing lead arsenate. On the following day, the beetles that had taken rotenone ate less untreated foliage than did those that had taken lead arsenate. Davidson therefore suspected a repellent action of rotenone. The writer believes that no repellent action was demonstrated. The beetles probably ate sublethal doses of rotenone and were affected to the extent that they were unable to feed normally on untreated leaf disks until they had recovered. Undoubtedly the same effect could have been produced with lead arsenate if larger sublethal doses had been taken. In his quantitative tests of various stomach poisons, including rotenone, against the silkworm, Campbell has found that the most obvious

effect of nearly lethal doses is to prevent the larvae from feeding on untreated leaves for a period of time that depends on the quantity of the sublethal dose. When lethal doses of rotenone are taken, the silkworm does not eat again, but may remain alive for several days. It has been noted by several workers that the toxic action of rotenone is slow as compared with that of established insecticides. The silkworm is so slowly affected by rotenone that it may take a dose many times larger than the median lethal dose. Of course, the quantity of rotenone that an insect may eat in excess of the median lethal dose depends on the concentration of rotenone on the foliage, the feeding habits of the insect, and the specific reaction of the insect to rotenone.

In experiments by Davidson on the imported cabbage worm, which is very susceptible to rotenone, the larvae died without feeding when placed on cabbage or mustard plants that had been dipped in a suspension of rotenone. They also died without feeding when placed with untreated leaves in Petri dishes that contained circles of leaves or filter paper soaked in rotenone suspensions. A similar experiment was made with Mexican bean beetles with the same result when the filter paper was previously soaked in a 1:1000 suspension of rotenone. Although the latter experiments may indicate a repellent effect of rotenone, it is more probable that the insects were poisoned by contact so that they were unable to feed on the untreated leaves.

Robinson reported a few tests with rotenone against the western tent caterpillar in an insectary. Most of the caterpillars died that ate any of the foliage treated with rotenone at 1:1890 and 1:1260. Robinson noted that the toxic action was slow and that many of the caterpillars placed on the sprayed apple foliage fell to the table below. He therefore concluded that rotenone is repellent to the larvae. However, the caterpillars that fell from the foliage may have been irritated by handling. In Davidson's experiment with the eastern tent caterpillar, previously mentioned, he observed that the caterpillars ate little or none of untreated leaves after having fed on sandwiches containing rotenone. The writer believes that a toxic effect rather than a repellent effect was involved.

In a few additional experiments with rotenone as a stomach poison for the house fly, Davidson gave the flies a choice of poisoned and unpoisoned milk. As would be expected, the mortality was lower than in earlier experiments when the flies had access to poisoned food only. Davidson remarked that a satisfactory kill did not result after exposure for two days. Since comparisons were not made at the same time between poisoned food only, and poisoned food with unpoisoned food, it is impossible to say with certainty that rotenone had a deterrent effect on the flies, although such an effect is probable.

Tests of rotenone as a moth-proofing agent by Back and Cotton and by Moore have given the clearest evidence of a repellent or deterrent effect. When the larvae are placed in a Petri dish containing a half circle of cloth treated with rotenone and an untreated half circle, they at first distribute themselves over both pieces. Later the majority of the larvae are found on the untreated piece. Back does not consider rotenone repellent because the initial distribution of the larvae is uniform. Moore writes that rotenone has a very strong repellent effect because all the larvae feed on the untreated side. He says there is some doubt about its toxicity

to the larvae. Whether the effect is repellent or deterrent, it is certain that rotenone drives the larvae away to the untreated cloth where they feed normally.

With the exception of the case just mentioned, the writer does not believe that a repellent or deterrent effect of rotenone has been convincingly demonstrated in the experiments described above.

Discussion of toxicology. In order to account for the stomach action of rotenone, which is practically insoluble in water, it is necessary to assume that rotenone, like acid lead arsenate, is attacked by the digestive juices to form a soluble, absorbable poison. Whether in the gut of the silkworm rotenone is dissolved and absorbed as such or whether the actual toxic agent is a soluble derivative of rotenone is not yet known. It may be possible to find out whether rotenone is markedly soluble within the gut of the silkworm by a simple experiment. If a small quantity of large crystals of rotenone are fed to a larva, an absence of crystals in the excrement after 4 or 5 hours would indicate that they were dissolved within the gut. The presence of crystals in the excrement would, of course, make the experiment inconclusive unless it could be shown that the crystals were not those of rotenone. For comparison, a similar experiment might be made with the grasshopper.

Even in the susceptible silkworm the toxic action of rotenone is so slow as to suggest that some time is required for the solution of rotenone within the gut or for the formation of a soluble toxic decomposition product of it. No toxic water-soluble derivative of rotenone is yet known. Several insoluble derivatives prepared in the Insecticide Division of the Bureau of Chemistry and Soils were tested by Shepard, who used the sandwich method with the fourth instar silkworm. None of these compounds was as toxic as rotenone, and only dihydrorotenone was markedly toxic.

It should be said at this point that although rotenone is practically insoluble in water, its solubility curve in pure water and in water containing traces of dissolved substances has not been determined, partly because of experimental difficulties involved. It is by no means certain that a saturated solution of rotenone in water would be without effect on insects. A presumably saturated aqueous solution of rotenone should be made and all suspended particles removed by careful filtration. Insects known to be susceptible to rotenone should then be treated with the filtered solution.

Investigations are also needed on the solubility and toxicity of rotenone in buffered solutions approximating those in the alimentary tract of insects. Experiments should be made in vitro on the effect of digestive enzymes of insects on rotenone and on the effect of the filtered juice of the gut contents on it.

Value of rotenone for plant protection. In most experiments for the protection of plants over a period of time against insect attack, rotenone has been applied as a suspension in water made by adding a solution of rotenone in acetone to water. In many of the earlier experiments tannic acid was added to the acetone solution of rotenone in order to increase the dispersion and physical stability of the suspension of rotenone in water. Tannic acid, however, was found to reduce the insecticidal effectiveness of the suspension. Since the use of tannic acid as a protective colloid for rotenone suspensions is no longer advocated, experiments

in which it was used will not be mentioned in this review. In a few cases inert dusts containing a small percentage of rotenone have been used.

Representative results of laboratory tests of rotenone against codling moth are given in Table 2. In all tests the apples were sprayed with suspensions of rotenone in water with or without the addition of other substances. Hough does not state how his suspensions were made, but Spuler and Newcomer added a solution of rotenone in acetone to water to obtain the suspensions except in a few experiments where rotenone was stirred in water to form the suspension. Spuler placed newly hatched larvae on the fruit within 24 hours after the application of the spray. Hough attached pear leaves bearing codling moth eggs to the side of the apples, which had been given two successive applications of each spray to insure thorough coverage. The eggs hatched during a period of time up to 72 hours after the application of the spray. Newcomer sprayed apples on the trees in the orchard. All leaves near the apples were removed so that no spray would be rubbed off. For the tests the apples were brought into an outdoor insectary and codling moth eggs just ready to hatch were placed on them.

The results in Table 2 are significant and consistent. Rotenone alone at 1:3340 and 1:4450 was decidedly more effective than lead arsenate at 2 pounds to 100 gallons (1:416) when the tests were made shortly after the application of the spray. However, Newcomer found that when the tests were made 7 days after the application of the spray the effectiveness of rotenone was markedly reduced whereas the effectiveness of lead arsenate remained about the same. Hough also noted the same phenomenon in a test of rotenone with Penetrol. Of the larvae that hatched from 6 to 48 hours after the application of the spray, 6.8 per cent entered the fruit; of those that hatched from 48 to 72 hours after the application 25 per cent entered. An experiment by Lathrop supports results of Newcomer and Hough. Using a 1:4450 suspension of rotenone, Lathrop found that 97.4 per cent of the number of larvae that entered the untreated apples were prevented from entering apples freshly treated with rotenone. However, when the larvae were placed on the fruit several days after treatment with rotenone, its efficiency was found to be only 32.5 per cent.

Newcomer, Hough and Lathrop do not mention any observations that might indicate whether the decline in effectiveness of rotenone is due to mechanical loss of part of the coating or to decomposition. The fragmentary evidence at hand leads the writer to believe that decomposition plays a major part in the decline in effectiveness of rotenone spray deposits. In addition to rotenone at 1:3340 (Table 2), Newcomer tested rotenone at 1:1110 (12 oz./100 gal.). Presumably the fruit treated with the latter mixture was more heavily coated, yet the effectiveness of the deposit was greatly reduced in 7 days. Furthermore, Newcomer was careful to prevent the deposit from being rubbed off. It may be assumed that no rain occurred. The reduction of effectiveness in Hough's experiment apparently occurred while the sprayed apples were hanging in a screened outdoor insectary where they were protected from rain. In Davidson's greenhouse experiment with the imported cabbage worm, previously mentioned, the larvae were placed on the dipped plants at intervals after the treatment. Those that were placed on the plants 10 days after treatment were killed but they were able to feed on the plants, whereas those placed on the plant up to 6 days after treatment died without feeding. Ginsburg has contributed the strongest toxicological evidence for the decomposition of spray deposits of rotenone. He placed

Table 2. Laboratory tests of rotenone in comparison with lead arsenate against codling moth.

Observers	Material	Concentration	No. of larvae	Period of hatching after spray application	Stings	Entrances
				hours	per cent	per cent
Spuler and Griffin	Rotenone	3 oz./100 gal.(1:4450)	100	0-24(?)	--	9.3
	Rotenone (without acetone)	do	do	do	--	20.6
	Rotenone and fish oil	do	do	do	--	8.2
	Lead arsenate	2 lbs./100 gal.	do	do	--	45.0
Newcomer and Dean	Rotenone	4 oz./100 gal.(1:3340)	150	do	3.3	16.7
	Rotenone (without acetone)	do	do	do	8.0	22.7
	Rotenone and starch	do 3 oz./100 gal.	do	do	6.7	36.0
	Rotenone and glue	4 oz./100 gal. 3 oz./100 gal.	148	do	5.4	59.5
	Lead arsenate	2 lbs./100 gal.	150	do	12.7	58.0
	Rotenone	4 oz./100 gal.(1:3340)	do	168-192(?)	4.7	76.7
	Rotenone (without acetone)	do	do	do	3.3	50.7
	Lead arsenate	2 lbs./100 gal.	do	do	11.3	53.3
Hough	Rotenone and Penetrol	1:1000(13.4 oz./100 gal.) 2:1000	132	6-48	2.3	6.8
	Rotenone and Penetrol	do	326	48-72	1.5	25.0
	Lead arsenate	4 lbs./100 gal.	463	48-72	15.3	0.6
	Rotenone and fish oil	1:1000(13.4 oz./100 gal.) 1:800	435	24-72	3.9	12.4
	Lead arsenate	4 lbs./100 gal.	612	24-48	26.2	1.9
	Rotenone and soap	1:2000(6.7 oz./100 gal.) 1:500	440	46-72(?)	0.2	5.4
	Lead arsenate	4 lbs./100 gal.	803	48-72	30.1	0.2

silkworms on a mulberry bush shortly after treating it with rotenone. A high mortality of the larvae resulted. After 6 days, however, silkworms were able to feed with impunity on the sprayed foliage, although no rain had fallen during that period. Davidson and Jones (8) and Jones and Haller (10) have shown that rotenone is oxidized by air in certain solvents to form yellow, non-toxic compounds called dehydrorotenone and rotenonone. Very recently Jones and Smith have found that rotenone deposits on glass slides turn yellow after a few days' exposure to sunlight. Preliminary tests by Gersdorff on goldfish and by Davidson on aphids and greenhouse whitefly showed that the yellowed deposits were much less toxic than the original deposits of rotenone. No doubt in laboratory tests it will be found that a rotenone spray coverage on apples will remain white and retain its effectiveness when the fruit is stored in the dark, but will turn yellow and lose its effectiveness when exposed to sunlight. (See the section on rotenone as a moth-proofing agent for further discussion of the effect of light on its insecticidal value.)

Another interesting point is brought out in Table 2. In all tests by Newcomer and Hough the percentage of stings on apples treated with rotenone was lower than that on apples treated with lead arsenate. In Hough's tests very few larvae succeeded in entering the apples that were heavily coated with lead arsenate, and the percentage of stings was high, showing that many larvae were poisoned as they attempted to enter the fruit. A larger, but still small, number of larvae entered the fruit treated with rotenone, but the percentage of stings was negligible. It looks as though lead arsenate acted chiefly as a stomach poison and rotenone chiefly as a contact poison. It is not clear, of course, how dry rotenone can act by contact, but according to Davidson (6) it does so act when dusted on certain larvae. Presumably the codling moth larva picks up particles of rotenone on its body as it crawls over the surface of treated fruit. A microscopical study of the behavior of codling moth larvae on surfaces treated with rotenone would be instructive.

No substances that have yet been added to rotenone in laboratory tests against the codling moth have materially increased its immediate effectiveness or have prevented decline in effectiveness during a period of exposure of the spray deposit. Assuming that decline in effectiveness was due to mechanical loss of rotenone, Newcomer added starch and glue as stickers, but found that both reduced immediate effectiveness considerably. The addition of mineral oil and fish oil emulsions to rotenone suspensions appears to have no significant effect in immediate tests. No delayed tests of combinations of oil emulsions and rotenone without tannic acid have been made.

Hough's experiment with rotenone and soap (Table 2) should be given particular attention, because it has been supposed that combinations of rotenone and soap would quickly lose their effectiveness as a result of decomposition of rotenone in the slightly alkaline soap solution. In this experiment excellent results were obtained three days after the application of the spray. On the basis of total injuries rotenone-soap was distinctly superior to the lead arsenate check. Hough noted that the addition of soap materially improved the distribution of rotenone. Further experiments should be made with rotenone and soap, both alkaline and neutral and containing free fatty acids. Experiments are also needed on the effectiveness of rotenone when mixed with fungicides.

Several field tests of rotenone against codling moth have been made in the Pacific Northwest. Examples of the results of such tests are given in Table 3. In all cases rotenone was dissolved in acetone and the solution was added to water in the spray tank to form a suspension of rotenone.

Table 3. Field tests of rotenone in comparison with lead arsenate against codling moth.

Observer	Compound	Concentration	Spray schedule	Per cent apples wormy and stung
Newcomer	Rotenone	8 oz./100 gal. (1:1670)	Calyx and first cover spray of lead arsenate followed by 6 cover sprays of rotenone	70.4
	Lead arsenate	2 lbs./100 gal.	Calyx and 6 cover sprays	51.5
Robinson	Rotenone	90 grams/100 gal. (1:4200)	Calyx and 3 cover sprays. Tannic acid was added to first cover spray	41.5
	Lead arsenate	3 lbs./100 gal.	Calyx and 3 cover sprays	9.3
Spuler	Rotenone	3 oz./100 gal. (1:4450)	Calyx spray of lead arsenate followed by 6 cover sprays of rotenone	17.0
	Lead arsenate	3 lbs./100 gal.	Calyx and 6 cover sprays	2.5

Those who have tested rotenone in the field against codling moth do not as yet consider it a promising substitute for lead arsenate. However, it is so effective in laboratory experiments when freshly applied that the possibility of its use in the field should not be abandoned until efforts have been made to understand and control its adherence and decomposition on fruit and foliage.

Runner failed to control the grape berry moth with a suspension of rotenone (1:3785).

Worthley tested rotenone as a dust with talc as a carrier against the European corn borer. A certain number of eggs (from 598 to 679) were seeded into each of four plots of sweet corn, which were then dusted as follows: (1) with 5 per cent rotenone, (2) with 1 per cent rotenone, (3) with 0.33 per cent rotenone, and (4) with pure talc. On the check plots 2450 eggs were placed. After a period not stated, a search was made for living larvae. Six larvae or 0.88 per cent of the number of eggs were found in (1), 44 or 7.12 per cent in (2), 52 or 8.55 per cent in (3) and 50 or 8.36 per cent in (4). In the check plots 305 or 12.51 per cent were recovered. Only the 5 per cent rotenone dust was markedly effective.

Chamberlin tried rotenone as a spray and dust against the tomato worm on tobacco. The preparation contained 0.5 per cent rotenone in an inert carrier. The effectiveness of a 1 per cent suspension of this preparation was compared with that of a 1 per cent suspension of lead arsenate, both applied as a spray on growing tobacco plants. Larvae of the third and fourth instars were allowed to feed on

the sprayed plants until they died or until the end of five days. Lead arsenate killed all the larvae during the first 24 hours. The rotenone preparation killed only 26 per cent of the larvae during five days. Similar results were obtained when the rotenone preparation was used as a dust at 8 to 9 lbs. per acre. The failure of rotenone to cause a greater mortality may have been due not only to decomposition and weathering but to the small quantity of rotenone that was applied per unit area of leaf surface.

Howard reported the failure of a dust containing 0.15 per cent rotenone to protect beans from attacks of the Mexican bean beetle. Two applications of 20 to 25 lbs. per acre were made, which gave some temporary protection, but at the close of the experiment 25 days after the second treatment, the foliage had been destroyed while the magnesium arsenate plots remained green. Howard also used concentrated aqueous suspensions of rotenone in cage tests against the Mexican bean beetle with disappointing results. Davidson, however, killed the beetle with a dilution of 1:10,000.

Although none of the foregoing field tests was exhaustive, it is probably significant that none gave promising results. It is evident that more should be learned about the decomposition, weathering and toxicology of rotenone, before further field tests are made.

Rotenone as a moth-proofing agent. In December, 1930, Back, Cotton, and Roark (1) published a note on rotenone as a moth-proofing agent. They stated that solutions containing 1 per cent to 2 per cent of rotenone dissolved in acetone, if used thoroughly to impregnate woolen goods, impart a resistance to fabric pests that is of practical value. By this treatment fabrics were protected against the attacks of the webbing clothes moth, the furniture carpet beetle, and the black carpet beetle. The tests were made in Petri dishes by the full circle and half circle method; i.e., some dishes contained a full circle of treated fabric and others a half circle of treated fabric and a half circle of untreated fabric. The dishes were kept in a place where the light was subdued. Back has informed the writer that fabric so treated has retained its resistance to attack for over a year.

Moore repeated the tests of Back, Cotton, and Roark and obtained the same results. However, he found that when treated fabric is exposed to sunlight or ultraviolet light it loses some of its resistance to attack. Moore used a solution of rotenone in a mixture of acetone and naphtha. A piece of cloth, after being dipped, was run through a wringer and thoroughly dried before being tested. At the close of an experiment the numbers of holes in the cloth were counted. More than 25 holes were called 25+. The number and age of the larvae used in the tests are not given in the report. No information is given on the period of the tests or on the length of time that rotenone protects fabric from attack in the dark or in subdued light. The results that bear upon the effect of light on rotenone are given in Table 4. The experiments in brackets are half circle comparisons, both half circles being treated.

The first six experiments show that light or heat causes the fabric to become less resistant to attack. The sixth experiment indicates that more than half of the quantity of rotenone exposed to sunlight was chemically changed or lost. The last

three experiments were designed to show that light rather than heat is responsible for the decrease in effectiveness of treated cloth exposed to light. In view of the previously mentioned results of Jones and Smith on the yellowing and detoxifying action of light on rotenone deposits on glass slides, it is very likely that a photochemical reaction was solely responsible for the effects observed.

Table 4. Moore's data on the effect of light and heat on rotenone as a moth-proofing agent. Half circle tests.

Experiment No.	Concentration of rotenone	Light	Temperature	Period of exposure of treated cloth before tests	Number of holes Treated	Number of holes Untreated
	per cent			weeks		
1	1	None	?	?	0	25 +
2	1	Sunlight at window	?	3	4	25 +
3	1	Daylight	?	3	4	25 +
4	1	Ultraviolet	?	0.65	9	25 +
5	1	None	?	?	0	—
	1	Sunlight	?	3	15	—
6	0.5	None	?	?	0	—
	1	Sunlight	?	3	7	—
7	1(?)	None	78-86°F	6	0	—
	1(?)	None	cool	6	0	—
8	1(?)	None	78-86°F	16	0	—
	1(?)	None	cool	16	0	—
9	1(?)	None	cool	6	0	—
	1(?)	Sunlight	?	?	12	—

If rotenone has any fumigating action, one would expect it to become evident in Petri dish tests of rotenone as a moth-proofing agent. However, no effect has been observed that could be attributed to the action of rotenone in the vapor phase. Reynolds has tried to detect some action of rotenone in small closed spaces in which the insects were prevented from coming in contact with rotenone crystals. The results of the experiments were either negative or contradictory. His tests with house flies were repeated by Campbell and Sullivan with negative results. It may be said that no fumigating action of rotenone has been demonstrated. This is not surprising, for a compound that melts at 163°C. would not be expected to liberate an effective vapor at ordinary temperatures.

Miscellaneous observations. Lehman tested a wireworm bait containing 10 grams of ground whole wheat, 1 gram of rotenone, and 6 grams of water. The ball of bait was placed in a salve tin containing 16 mesh soil, and 25 wireworms that had starved for two months were placed in the tin. Five such tins were set up and the larvae were examined after two weeks. Since the greatest mortality was only 24 per cent, the results were not considered promising. This experiment brings up the question of the effect of soil microorganisms on rotenone. If rotenone is not toxic to fungi, bacteria, and protozoa, these organisms might be expected to decompose it.

Wood should be impregnated with rotenone to determine its effectiveness against termites. It would be interesting to find out whether rotenone has any effect on the intestinal protozoa of termites.

Roark has received cube root that was riddled by tunnels of a bostrichid beetle.

Haag (9) observed that blowfly maggots developed normally upon food sprinkled with rotenone crystals. The question of bacterial action on rotenone again arises.

Contact action

Rotenone as an aphicide. In general, rotenone has given better practical results as a contact insecticide than as a stomach poison. Since it has been studied most extensively as an aphicide, the results of tests on aphids will be summarized and discussed in some detail. A compilation of data is given in Table 5.

All species of aphids used, with the exception of the woolly apple aphid, were killed by dilute aqueous suspensions of rotenone. When comparisons were made with nicotine or nicotine sulphate, rotenone was more effective, except in the case of the woolly apple aphid. The greater susceptibility of the woolly apple aphid to nicotine is probably due to the fumigating action of nicotine.

It is remarkable that many species of aphids are killed by dilute aqueous suspensions of rotenone in the absence of a wetting and spreading agent. How does the poison reach the tissues of the insect? It is not likely that particles of rotenone enter the mouth or spiracles. It is more reasonable to assume that rotenone is sufficiently soluble in water or in the secretions of the insect to penetrate the cuticula or intima in solution. Minute droplets of rotenone suspensions should be placed on the integument of aphids to find out whether the insects will die when the only possible path of entrance of the poison is through the integument.

Though stomach action of rotenone is not likely in aphids, the possibility of its occurrence should not be overlooked. An observation by Davidson (6) may be significant in this connection. He found that rotenone continues to be active on the plant for several days after spraying, many of the young aphids that were deposited on the treated portions of the plants being killed. Rotenone or a toxic product of it might penetrate foliage and make the plant juices toxic to aphids. Plants should be sprayed with rotenone, washed, and infested with aphids to study this possibility. The poison might also diffuse into the leaf around the beak and so be drawn into the alimentary tract.

Table 5 shows that rotenone acts slowly as a contact poison when applied in dilute suspensions. Davidson (6) found it necessary to make observations over a period of several days in order to determine the total mortality of the aphids. Against the bean aphid he obtained a high mortality with a dilution of 1:300,000, whereas Shepard (12), working with the same species, required a dilution of 1:10,000 for the same results because he made his counts at the end of 24 hours.

The effect of wetting and spreading agents on the effectiveness of rotenone

Table 5. Tests of aqueous suspensions of rotenone sprayed on aphids.

Observer	Insect	Plant	Place	Stock solution	Spreader	Period between treatment and final count	Lowest concentration of aqueous suspension to kill at least 90 per cent of aphids
						days	gram: c.c.
Darley (5)	Turnip aphid	Cabbage	Field	0.2 gm. to 5 c.c. benzine+95 c.c. Penetrol	Penetrol 1:300	2	1:150,000
do	Spiraea aphid	Spiraea	Laboratory	2 gm. to 100 c.c. acetone	Penetrol 1:200	2	1:100,000
Shepard (12)	Bean aphid	Nasturtium	do	0.25 gm.to 100 c.c. 95% ethyl alcohol	None, Saponin 1:100, soap 1:333	1	1:10,000[2]
Ginsburg	Apple aphid, rosy apple aphid	Apple	do	1 gm.to 100 c.c. acetone	None	do	1:80,000[2,3]
Davidson (8)	Cabbage aphid, green peach aphid	Cabbage	Greenhouse	0.175 gm.to 100 c.c. acetone	do	7	1:100,000[1]
Davidson (6)	do	do	do	4 gm.to 100 c.c.acetone	do	several	1:200,000[1]
do	Bean aphid	Nasturtium	do	do	do	do	1:300.000[1]
do	Apple aphid, rosy apple aphid	Apple	Field	do	do	do	1:60,000[1]
do	Black peach aphid	Peach	do	do	do	do	1:40,000[1]
Newcomer	Apple aphid	Apple	do	Acetone solution	do	1	1:3,340[1]
do	Woolly apple aphid	do	do	do	None, fish-oil soap 1:840, 1:420	?	do[1,2]
Yothers	Apple aphid	do	Laboratory (outdoors)	?	None, soap 1:210, Penetrol 1:200 gal.	3	1:1670[1]
do	Woolly apple aphid	do	do	?	Soap 1:210	3	do[2]

[1]Lowest concentration tested.
[2]Other applications with suspensions of the same or higher concentrations killed less than 90 per cent.
[3]Aphids were dipped in the suspension.

suspensions as aphicides has not yet been studied sufficiently to warrant generalizations. Shepard (12) compared the effectiveness of a 1:10,000 suspension of rotenone with suspensions of the same concentration containing saponin (1 per cent) or sodium fish-oil soap (0.3 per cent). Owing to the variability of the resistance of the aphids, definite conclusions can not be made, but the indications are that saponin decreased the effectiveness of fresh preparations, while soap may have increased their effectiveness. The same mixtures, allowed to stand, were tested from time to time over periods of a month or more, with the result that the rotenone-soap mixture appeared to lose part of its original effectiveness, but the deterioration, if any, was certainly neither rapid nor extensive. However, there is no doubt that a 1:10,000 suspension of rotenone in a 0.01 N solution of sodium hydroxide lost much of its effectiveness after standing for eight days.

In rough field tests against the woolly apple aphid, Newcomer compared the effectiveness of rotenone suspensions with and without soap, and also compared the fresh preparations with those that had stood 24 hours. Soap appeared to make rotenone more effective. All preparations that had stood for 24 hours before application seemed to be less effective than the fresh preparations. Owing to the uncertain character of the foregoing results, it would be desirable to make an extensive series of experiments on aphids to determine definitely the effect of various concentrations of wetting and spreading agents on the effectiveness of fresh rotenone suspensions. The results should be correlated with the wetting and spreading power of the spray and with its pH. More extensive experiments should also be made on the deterioration in effectiveness of rotenone suspensions on standing, with and without wetting and spreading agents.

<u>Rotenone as an acaricide</u>. Against the common red spider on the Kudzu vine in a greenhouse, H. H. Richardson proved that wetting and spreading agents greatly increase the effectiveness of rotenone suspensions. The experiments were carefully controlled and mortality counts were made after 24 hours. Rotenone at 1:5000 killed 12 per cent of the adult mites. At 1:5000 plus potassium oleate (1:400) from 54 to 78 per cent of the mites were killed. The soap solution alone killed from 9 to 11 per cent, a mortality not much greater than that in the untreated checks. The increased effectiveness of the rotenone-soap mixtures was therefore due to rotenone aided in some chemical or physical way by potassium oleate. Rotenone at 1:1000 with potassium oleate (1:400) killed only 67 and 83 per cent of the mites, a five-fold increase in concentration producing very little increase in mortality. Davidson (6) killed 64.5 per cent of the mites with rotenone at 1:1000 without a wetting and spreading agent, but since his methods are not described, his result does not necessarily contradict those of H. H. Richardson. Adding Penetrol to rotenone suspensions, Darley (5) killed 75 per cent of the mites in 24 hours with rotenone at 1:100,000 and 90 per cent at 1:50,000,--much greater dilutions than those used by H. H. Richardson. Whether Penetrol increases the effectiveness of rotenone suspensions more than potassium oleate does can be determined only by paired experiments. H. H. Richardson also tested sulphonated castor oil as a wetting and spreading agent for rotenone suspensions, and found it less effective than potassium oleate. Both H. H. Richardson and Darley (5) found that rotenone with wetting and spreading agents was more effective against the common red spider than were the pyrethrins or nicotine with the same agents.

<u>Miscellaneous tests</u>. Rotenone has been tested as a contact insecticide against many other species of insects. Davidson (6) has published the results of an extensive

survey of the possibilities of rotenone as a contact insecticide. His results against aphids, common red spider, and culicine mosquito larvae have already been mentioned. Other results are classified in Table 6 by concentrations of rotenone suspensions without spreader required to kill 90 per cent or more of a population. A 90 per cent kill was not attained at the highest concentrations used against the following species: Citrus mealybug, German cockroach, common red spider, squash bug, spotted cucumber beetle.

Table 6. Davidson's tests of rotenone in aqueous suspension as a contact insecticide. Without spreader.

Lowest concentration that killed at least 90 per cent of the insects	Plant	Insect
1:100,000	bean	Greenhouse whitefly, larvae
	grape	Grape leafhopper, nymphs
Between 1:100,000 and 1:10,000	bean	Onion thrips, larvae and adults
	Plantago	Thrips sp.
	plum and apple	Eastern tent caterpillar, young larvae
	potato	Colorado potato beetle, larvae
	bean	Mexican bean beetle, young larvae
1:5000	bean	Mexican bean beetle, adults

Darley (5) tested rotenone suspensions against some of the species used by Davidson and obtained similar results. Spotted cucumber beetles, squash bugs and citrus mealybugs were resistant to rotenone even though Penetrol was added to the suspensions.

Ginsburg compared the susceptibility of aphids and honey bees to rotenone suspensions without spreader. A dilution of 1:160,000 killed 83.2 per cent of the aphids and one of 1:5000 killed 74.5 per cent of the bees in 24 hours. Honey bees are evidently more resistant to rotenone suspensions than are aphids.

Campbell and Sullivan find that house flies are among the species most resistant to aqueous suspensions of rotenone. Suspensions of 1:5000 apparently have no

effect on house flies, though when the flies are examined under the microscope after the treatment crystals of rotenone can be seen distributed over the integument.

The foregoing results on the contact action of rotenone suspensions in water show differences in resistance of species ranging from the high susceptibility of aphids to the complete resistance of mealybugs. The data now at hand do not permit of any explanation of the differences observed, though it may be assumed that the more resistant species are those that rotenone or its toxic derivatives do not easily touch or enter. Rotenone should be injected into susceptible and resistant species to find out to what extent internal factors determine susceptibility.

In addition to testing aqueous suspensions of rotenone, Davidson (6) applied rotenone as a 1 and 2 per cent dust in diatomaceous earth. The small sucking insects were not killed as readily by the dust as by the suspensions. On the other hand, the dust was more effective than the suspensions against chewing insects: Imported cabbage worms, Mexican bean beetles, and German cockroaches. It might be supposed that the dust acted against the species just named by way of the alimentary tract, but Davidson (6) states that the cabbage worms and bean beetle larvae died "almost instantaneously and were evidently killed by contact." This is an exception to the general rule that rotenone acts slowly.

Davidson has also tested mixtures of rotenone and various colloidal carriers as sprays. The dry mixtures contained 10 per cent rotenone in bentonite, saponin, or gum acacia. For spraying, suspensions of the mixtures were made containing known concentrations of rotenone. Against the green peach aphid these suspensions containing 1 gm. rotenone to 100,000 c.c. of water were not as effective as a suspension without colloid (water-acetone method) containing the same quantity of rotenone.

Rotenone as a house fly spray. Against the house fly rotenone need not be applied in suspension in water, but may be applied in solution in an organic solvent. Kerosene, so largely used as a solvent and carrier for the pyrethrins in household sprays, is not a good solvent for rotenone. However, the effectiveness of a saturated solution of rotenone in kerosene has not yet been determined. It has seemed more promising to mix kerosene with a solution of rotenone in an organic liquid that is miscible with kerosene, the mixed solvents carrying a higher percentage of rotenone in solution than would kerosene alone. Davidson has tested a 1:2000 solution of rotenone in kerosene-ethylene dichloride in a standard fly chamber (6' x 6' x 6') at temperatures ranging from 69° to 88°F. Five tests were run and each test was paired with a check of the mixed solvent without rotenone. From 11 to 33 c.c. of the liquid was sprayed into the chamber, half through a hole in one side and half through a hole in the opposite side. The mixed solvents alone had little or no effect on the flies, but the rotenone solutions paralyzed from 29 to 84 per cent of the flies in 10 minutes depending on the volume of the solution sprayed into the chamber. Commercial pyrethrum fly sprays when tested in the same way paralyze a larger percentage of flies, but rotenone sprays may kill a greater percentage of those that are affected. In Davidson's test with 33 c. c. of the rotenone solution, 43 out of 51 flies were brought down and 42 of these died.

By treatments in the cold described in the next paragraph, Campbell and Sullivan compared the effects on house flies of 1:10,000 solutions of the pyrethrins

and of rotenone in absolute alcohol. A very marked difference in the initial and final effects of the sprays was observed. At first all the flies were paralyzed by the pyrethrins, while none were visibly affected by rotenone. Then as the flies treated with the pyrethrins began to recover, those treated with rotenone began to be affected. After 24 hours practically all the flies treated with the pyrethrins had recovered, while a considerable number were dead or dying from the effects of rotenone. The final 48 hour count showed a 2 per cent mortality for the pyrethrins and a 22 per cent mortality for rotenone. It is obvious that it might be advantageous to apply the pyrethrins and rotenone together in order to utilize simultaneously the rapid paralyzing action of the one and the slow killing power of the other. Abbott has informed the writer that such combinations are indeed promising and that insecticide manufacturers are experimenting with them. From a toxicological point of view it would be desirable to test the pyrethrins and rotenone together and separately in order to determine to what extent their combined effect is additive.

House flies are being used by Campbell and Sullivan as test insects for the determination of the relative toxicity of rotenone and related compounds.[4] The spraying chamber consists of a glass cylinder 8½ inches in diameter and 17 inches high and a bell jar of the same diameter and 13 inches high which rests on top of the cylinder. The cylinder stands on a shallow copper tray in which the flies are confined. The top of the tray can be opened or closed at will by a sliding copper plate. A spray gun is mounted in the hole at the top of the bell jar and is connected to a compressed air line. The flies in the tray at the bottom of the cylinder can be sprayed directly or by manipulation of the copper plate can be exposed for any desired period to a settling fog of the spray. Treatments may be made either in the cold or at room temperature.

When the treatments are made in a cold room at 32° F., 50 immobile flies are placed on their backs on a circle of filter paper on the bottom of the tray. After the treatment the flies are transferred to cages which are placed immediately in a high temperature room at 83° to 84° F. Here the flies regain their mobility in about 5 minutes and the poison takes effect. Counts of dead and dying flies are made at the end of 46 to 48 hours. Under these conditions an acetone solution of rotenone (1:5000) kills about 40 per cent of the flies. When active caged flies are treated in the same way at room temperature, the 1:5000 solution kills about 90 per cent.

Tests in the cold room have led to one significant result that could not have been obtained at higher temperaatures. With immobile flies it was shown that the effect of the 1:5000 treatment depends on the position and exposure of the insect's body with respect to the settling fog. When the flies were placed on their feet so that the fog settled on the wings and dorsum, they were not affected. When they were placed on their backs so that the fog fell on the venter and pleural area, many were killed. When they were placed on their backs and the heads or abdomens were covered, the mortality was greatly reduced, indicating that the poison probably enters all three regions of the body when the flies on their backs are fully exposed.

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[4]This is a cooperative project with the Insecticide Division of the Bureau of Chemistry and Soils. The derivatives of rotenone are being made by F. B. LaForge, H. L. J. Haller and L. E. Smith. W. A. Gersdorff is testing them against goldfish and C. M. Smith and H. A. Jones are studying the effect of light on some of them.

Although the treatments in the cold are of the greatest possible uniformity, the results from day to day seem to vary as much as those obtained at higher temperatures. For convenience, therefore, recent tests have been made at 83° to 84° F. with the apparatus described above. For each test 50 chilled flies 2 days old are counted out into a large Petri dish which is then covered with wire screen. When the flies have resumed their normal activity, the dish is placed in the bottom of the copper tray and the spraying chamber is assembled above it. Absolute ethyl alcohol is used as the solvent for rotenone and related compounds because it has no permanent effect on the flies. Alcohol is preferred to acetone for work at high temperatures because it does not evaporate so rapidly. At 20 lbs. pressure about 10 c.c. of the alcohol solution is sprayed into the chamber with the flies exposed. The spraying operations takes about 10 seconds, after which the flies are exposed to the settling fog for 3 minutes. the flies are then transferred to a cage with food. Final counts of dead and moribund flies are made at the end of 46 to 48 hours. Results are expressed as per cent effect, each dead fly equaling 2 per cent and each moribund fly 1 per cent. The rearing, spraying and observation of treated flies are all done in the same constant temperature room. Details of methods and precautions taken to prevent contamination and to obtain uniform results are too numerous to be described here.

Under the conditions just outlined the following average results were obtained in terms of per cent effect of 1:5000 solutions: rotenone 86.4 per cent (10 tests), dihydrorotenone 65.5 per cent (10 tests), rotenone hydrochloride 30 per cent (10 tests), acetyl rotenone 25 per cent (7 tests). The following compounds produce less than a 10 per cent effect and hence can not be classified in order of value until tested at higher concentrations: isorotenone, desoxyrotenone, dehydrorotenone, rotenonic acid, dihydrorotenonic acid, acetyl rotenolone, and acetyl dihydrorotenolone.

It is noteworthy that Gersdorff placed the first four compounds in the same order of value as a result of his tests against goldfish. As previously mentioned, Shepard found that dihydrorotenone is nearly as toxic as rotenone as a stomach poison for the silkworm. Consequently it is believed that rotenone is more toxic than any of its derivatives that have yet been tested and that dihydrorotenone is the most toxic of these derivatives, being almost as good as rotenone. The most toxic derivatives of rotenone seem to be those that depart least from its structure.

The effect of light on dihydrorotenone is now being studied and already there is evidence that it may be more resistant than rotenone to detoxication.

Rotenone for the control of insect pests of animals. Davidson (6) dusted chickens with diatomaceous earth containing 1 and 2 per cent rotenone. All the body lice and the shaft lice dusted with the 2 per cent mixture dropped off within 48 hours. The 1 per cent mixture freed the chickens of lice in 3 days. A 0.1 per cent rotenone dust was effective on body lice, but ineffective against shaft lice. A 1 per cent rotenone dust removed fleas from dogs.

Wells reports tests of rotenone for the control of the common cattle grub. He applied to the backs of infested cattle dusts containing 0.5 to 2 per cent rotenone and cottonseed oil containing 0.5 per cent rotenone. Best results were obtained with the latter mixture, 94 per cent of the grubs being killed in a week. The dusts killed about 75 per cent of the grubs. Well concluded that thoroughness of application is more important than the percentage of rotenone in the mixture

Insecticidal value of extracted root (marc) of derris and cube. In a very comprehensive investigation of derris as an insecticide at a time when rotenone was not known in this country, McIndoo, Sievers and Abbott (11) tested derris powder and many different extracts from it against a number of species of insects. Their results were qualitatively similar to those obtained with rotenone which are described in this review. They noted the slow action of derris, which is also characteristic of rotenone.

McIndoo, Sievers and Abbott (11) were able to extract derris root so thoroughly that the marc had little or no effect as a stomach poison for honey bees in comparison with the effect of the extract. More recent experiments have indicated that the root extracted with ether may retain some of its original toxic properties. Bishopp, Laake, Wells, and Peters (2) have shown that the powdered root of derris and cube may give complete control of the common cattle grub. The rotenone content of some of their samples was known. One sample was tested from which rotenone had presumably been removed by extraction with ether. Nevertheless it was not without effect. Bishopp therefore believed that a good sample of powdered derris root would be preferable to a rotenone dust for the control of the common cattle grub. He supposed that rotenone had been completely extracted from the sample tested by him and that its toxicity was due to some other toxic compound that had not been extracted by ether.

Three other compounds related to rotenone; i.e. deguelin, tephrosin, and toxicarol, have been isolated from derris and cube by Clark (4). However, they are extracted along with rotenone and remain in solution in the mother liquor from which rotenone crystallizes out. Even if these compounds are not completely extracted by ether, it does not seem likely that the quantity remaining would make the marc appreciably toxic to insects, because Davidson (7) has shown that none of them is as effective as rotenone in aqueous suspensions against five species of insects. Deguelin, an isomer of rotenone, was the most effective of the three and toxicarol the least effective. Shepard placed them in the same order of relative toxicity as stomach poisons for the silkworm. None of them was as toxic as rotenone.

Following up Bishopp's observation that the extracted root might have some insecticidal value, Davidson tested several marcs against a number of species of insects. Usually he compared the effectiveness of extracted and unextracted powder from the same lot of root. In all cases he found that the marc, although less effective than the original root, still had some insecticidal value whether extracted with ether or with carbon tetrachloride, isopropyl alcohol, and acidulated water.

Campbell and Sullivan then made some preliminary experiments on this subject, using house flies. Active flies in Petri dishes were dusted in the apparatus previously described. Under certain conditions all the flies were killed by the original root while none was affected by the marc. The original root was so extremely effective that great precautions had to be taken to prevent contamination in comparative tests. When further experiments are made the writer will use powdered locust root as a check. The writer believes that it will be possible to demonstrate the complete removal of toxic substances from the marc.

Summary

Against certain insects rotenone as a stomach poison is more toxic than acid lead arsenate, and as a contact poison is more toxic than nicotine. Against some insects rotenone is highly effective; against others it is ineffective. Rotenone is generally slower in action than the better known insecticides.

Rotenone may have practical value as a contact insecticide against aphids and other soft-bodied insects. It may find a place in household insecticides and may be useful for the control of insect parasites of domestic animals.

Rotenone does not look promising for the protection of plants over a period of time against insect attack because its toxic properties are too quickly destroyed by sunlight.

It is still questionable whether the use of rotenone has any important advantage over the use of analyzed root of derris or cube or of crude extracts from the root.

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Appendix 1

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Appendix 2

List of names of species against which rotenone has been tested.
(According to latest list of approved names, Jour. Econ. Ent. 24: 1273-1310. 1931.)

Common name	Scientific name	Observer
American dog tick	Dermacentor variabilis Say	Davidson
Apple aphid	Aphis pomi DeG.	Davidson Ginsburg Newcomer Yothers
Bean aphid	Aphis rumicis L.	Davidson Shepard
Black carpet beetle	Attagenus piceus Oliv.	Back and Cotton Billings
Black peach aphid	Anuraphis persicae-niger Smith	Davidson
Cabbage aphid	Brevicoryne brassicae L.	Davidson
Carpet beetle	Anthrenus scrophulariae L.	Moore
Chicken body louse	Eomenacanthus stramineum Nitz.	Davidson
Citrus mealybug	Pseudococcus citri Risso	Darley Davidson
Codling moth	Carpocapsa pomonella L.	Hough Lathrop Newcomer Robinson Spuler
Colorado potato beetle	Leptinotarsa decemlineata Say	Davidson
Common cattle grub	Hypoderma lineatum DeVill.	Wells
Common red spider	Tetranychus telarius L.	Darley Davidson Richardson, H.H.
Confused flour beetle	Tribolium confusum Duv.	Billings
Differential grasshopper	Melanoplus differentialis Thos.	Davidson Richardson, C.H.
Dog flea	Ctenocephalides canis Curt.	Davidson

Eastern tent caterpillar	Malacosoma americana Fab.	Davidson
Eggplant lacebug	Gargaphia solanii Heid.	Davidson
European corn borer	Pyrausta nubilalis Hbn.	Worthley
German cockroach	Blatella germanica L.	Davidson
Goldenglow aphid	Macrosiphum rudbeckiae Fitch	Darley
Grape berry moth	Polychrosis viteana Clem.	Runner
Grape leafhopper	Erythroneura comes Say	Davidson
Greenhouse whitefly	Trialeurodes vaporariorum Westw.	Davidson
Green peach aphid	Myzus persicae Sulz.	Davidson
Harlequin bug	Murgantia histrionica Hahn	Davidson
Honey bee	Apis mellifera L.	Ginsburg
House fly	Musca domestica L.	Campbell and Sullivan Davidson
Imported cabbage worm	Ascia rapae L.	Davidson
Japanese beetle	Popillia japonica Newm.	Bottimer
Melon aphid	Aphis gossypii Glov.	Davidson
Mexican bean beetle	Epilachna corrupta Muls.	Davidson Howard
Onion thrips	Thrips tabaci Lind.	Davidson
Red-legged grasshopper	Melanoplus femur-rubrum DeG.	Richardson, C.H.
Rice weevil	Sitophilus oryzae L.	Billings
Rosy apple aphid	Anuraphis roseus Baker	Davidson Ginsburg
Silkworm	Bombyx mori L.	Campbell Davidson
Spotted cucumber beetle	Diabrotica duodecimpunctata Fab.	Darley Davidson
Squash beetle	Epilachna borealis Fab.	Davidson

Squash bug	Anasa tristis DeG.	Darley Davidson
Striped cucumber beetle	Diabrotica vittata Fab.	Davidson
Tomato worm	Phlegethontius sexta Johan.	Chamberlin
Turnip aphid	Rhopalosiphum pseudobrassicae Davis	Darley
Webbing clothes moth	Tineola biselliella Hum.	Back and Cotton
Western tent caterpillar	Malacosoma pluvialis Dyar	Robinson
Woolly apple aphid	Eriosoma lanigera Hausm.	Newcomer Yothers

(Species not found in list of approved names)

Black blowfly	Phormia regina Meig.	Haag
Chicken shaft louse	Menopon pallidum Nitz.	Davidson
Cutworm sp.		Reynolds
Furniture carpet beetle	Anthrenus vorax Casey	Back and Cotton
Mosquito (larvae)	Culex pipiens L.	Davidson Shepard
Spiraea aphid	Aphis spiraecola Patch	Darley
Thrips sp.		Davidson
Tulip tree aphid	Illinoia liriodendri Monell	Davidson
Wireworm	Pheletes canus Lec.	Lehman